Available online at www.sciencedirect.com

ScienceDirect

Procedia Materials Science 5 (2014) 267 – 273

Procedia Materials Science

www.elsevier.com/locate/procedia

International Conference on Advances in Manufacturing and Materials Engineering, AMME 2014

Tensile test simulation of CFRP test specimen using finite elements

Mayank Nirbhay[a]*, Anurag Dixit[a], R.K. Misra[a], Harlal Singh Mali[b]

[a]*School of Engineering, Department of Mechanical Engineering, Gautam Buddha University, Greater Noida, 201312, India*
[b]*Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur, Rajasthan, 302017, India*

Abstract

The present work intends to provide a numerical tool for the efficient design of the multidirectional carbon fiber reinforced plastic (CFRP) material using finite element simulation software ABAQUS®. A 3D model has been established for simulation of the tensile test composite specimen which enables to understand the mechanical strength and strain at failure of the composite materials. 15 ply CFRP specimens with various stacking sequences were analyzed for their strength and displacement. Exhaustive parametric studies reveal the dependency of reinforcing material and ply orientation on the strength and stiffness of composite materials. Carbon fibers with cross ply lamination were found to be stiffer than angle ply glass fiber lamination. A fairly good comparison was obtained between the predicted results with available experimental and theoretical data in open literature

Selection and peer-review under responsibility of Organizing Committee of AMME 2014

Keywords: carbon fiber reinforced plastics; stacking sequence; reinforcing material; ply orientation; cross ply; angle ply

1. Introduction

Polymer-matrix composite laminates are extensively used as load carrying members for different engineering structures. A soft and ductile polymer material called matrix is reinforced with stronger fibers to form these composites for specific engineering purposes (Dixit and Mali; 2013).Advanced composite materials are usually made from high strength fibers such as glass, carbon, aramid, boron etc. Each reinforcing fiber has its discernible properties which decide its suitability for various applications.A carbon fiber is a long and thin fibers having

* Corresponding author. Tel.: 9560076589
E-mail address: mayankgbu@gmail.com

2211-8128
Selection and peer-review under responsibility of Organizing Committee of AMME 2014
doi:10.1016/j.mspro.2014.07.266

diameter 5-10 μm. The crystal bonding of carbon atoms almost or exactly parallel to the longitudinal axis of the fiber makes very strong fibers as compared to their size (Sohna et.al;2000).

Carbon fiber-reinforced plastic CFRP’s present specific properties such as stiffness/weight and strength/weight ratios much higher than those of metallic materials. Much of the fuselage of the new Boeing 787 Dreamliner and Airbus A350 XWB will be composed of CFRP, making the aircraft lighter than a comparable aluminum fuselage, with the added benefit of less maintenance thanks to CFRP's superior fatigue resistance. Many supercars over the past few decades have incorporated CFRP extensively in their manufacture, using it for their monocoque chassis as well as other components. Carbon fiber-reinforced polymer has found a lot of use in high-end sports equipment such as racing bicycles (Tong et.al; 2002). Other sporting goods applications include rackets, fishing rods, long boards, and rowing shells. For the same strength, a carbon-fiber frame weighs less than a bicycle tubing of aluminum or steel.(CFRPs) have an almost infinite service lifetime when protected from the sun, and, unlike steel alloys, have no endurance limit when exposed to cyclic loading. Carbon/epoxy composite laminates have been accepted by the aircraft, aerospace and high end automotive industries on account of their high modulus, high specific strength, high stiffness, low density, ease of fabrication and the facility for tailoring in component design.

The main purpose of the present investigation is to calculate the strength and stiffness of CFRP test specimen using finite element simulation software ABAQUS®. The results from the present investigation are compared and verified with the published experimental and simulation results obtained by (Avdic and Saha; 2011). Moreover, a series of parametric studies were carried out in order to discuss the importance of material selection and ply orientation in composite laminates.

2. Theoretical background

Composite materials are mainly prepared by assembling or binding several distinctive layers of unidirectional lamina or ply such that the fiber orientation can vary among the lamina. Fig. 1 represents a unidirectional lamina or ply made up matrix and fiber with longitudinal and transverse directions. In order to simulate the mechanical behavior of composite specimen, stiffness of each lamina is to be calculated. The stiffness of the lamina and laminates depends upon various factors such as basic mechanical properties of the matrix and fiber, amount or volume fraction of the matrix and fiber in the composite material, type and orientation of reinforcement employed such as continuous or discontinuous fiber.

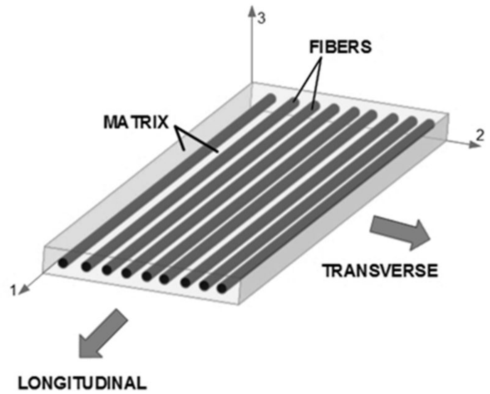


Fig. 1. Schematic representation of unidirectional lamina.

Rule of mixture model Voigt (1910) was used to calculate to calculate the lamina properties E_{11}, E_{22}, E_{33}, G_{12}, and G_{13}.

3. Finite Element Analysis:

With advancement in the computers, finite element analysis has emerged as one of the powerful tool available to engineers for use in design and analysis of complex problems. It has been successfully used for advanced numerical calculations and is originated from the theories of continuum mechanics, which studies equilibrium, motion and deformation of physical solids.FEM involves the approximation of continuous functions by a discrete model where the body to be examined is divided into several smaller parts, called elements (Swensson and Ingreffa; 1998). This meshed model is composed by a number of element functions that are continuous over each separate element. These elements are interconnected to each other through nodes. Numerical values for these nodes are compiled to make the element functions an accurate approximation of the global function. Accuracy generally improves with increase in the number of nodes.

In the present study the finite element simulation was carried out on a CFRP tensile specimen using commercially available software ABAQUS®which solve complex engineering problems ranging from linear to non-linear behaviour. Based on the tensile test experimental data (Avdic and Saha;2011). The finite element model of composite specimen under static load was modelled and stress analysis was carried out. The geometry of the test specimen is rectangular with length 300mm, width 25mm, thickness 2.7mm and margin of 57mm from each ends for gripping as depicted in Fig. 2. In order to replicate the real tensile test the boundary and loading conditions are applied as similar to the actual tensile test experiment. The lower grip of specimen was kept as fixed in all direction while the upper grip was kept as fixed in all directions but unconstrained in longitudinal direction i.e. free in the direction of load applied. The upper grip was loaded with a surface traction load of 31 MPa.

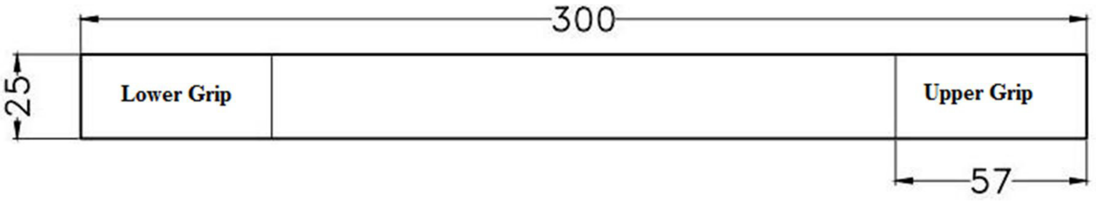


Fig. 2.Geometric model of the rectangular test specimen

The load in this particular simulation was applied using surface traction scenario keeping in mind the fact that displacement control results in a much more gradual failure as compared to loading done by applied forces method. It is observed that when a simple structure, such as composite plate begins to fail under the action of applied force the structure fails very rapidly because the load continues to increase thereby decreasing the load carrying capacity of the structure. On the other hand in displacement controlled loading the load carried by the structure decreases as the structure fails which allows for a slower rate of failure.

In order to obtain accurate stress distribution result in a reasonable analysis time, the structured meshing technique was used to mesh the model with S4R (Linear four noded general purpose shell element with reduced integration) with hourglass control. Four-node element means, every element consists of 4 nodes while reduced integration means that the order of integration is lower than that of full integration. The schematic of the FE model for the CFRP test specimen with loading and boundary conditions is shown in Fig.3.

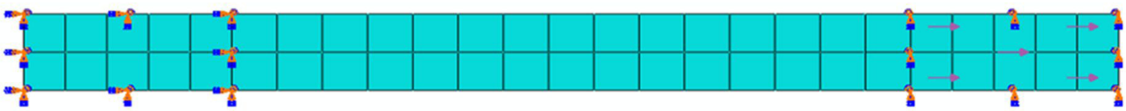


Fig. 3.FE model of test specimen with boundary and loading conditions

3. Material Definition

In the present investigation two different lamina type materials are created one for the carbon/epoxy and another for the glass/epoxy ply. From the mechanical properties of the T700 carbon fiber, E-glass fiber and matrix as shown in Table 1, the engineering properties of these two plies were calculated by using the rules of mixture. Table2 shows the engineering properties of the carbon-fiber epoxy ply and E-glass epoxy ply.

Table 1. Mechanical properties of constituents.

Constituent	E (GPa)	ν	V_f
T700 Carbon fiber	220	0.2	0.5
E-glass fiber	73	0.25	0.5
Matrix (Epoxy vinyl ester resin)	4.5	0.4	0.5

Table 2. Engineering properties of Carbon and E-glass fiber epoxy ply.

Property	Carbon/epoxy	E-glass/epoxy
E_{11} (GPa)	146.5	38.75
E_{22}=E_{33} (GPa)	109.62	8.47
G_{12}=G_{13}(GPa)	44.29	3.047
ν_{12}	0.3	0.325

The specimen was made up of 15 plies out of which 12 are of T700 carbon/epoxy and the remaining three plies are of E-glass/epoxy composite material. Each ply was assigned its material, region, thickness and orientation as shown in Figure 4 and Table 3. The gauss integration rule with three integration point approach was preferred in this simulation.

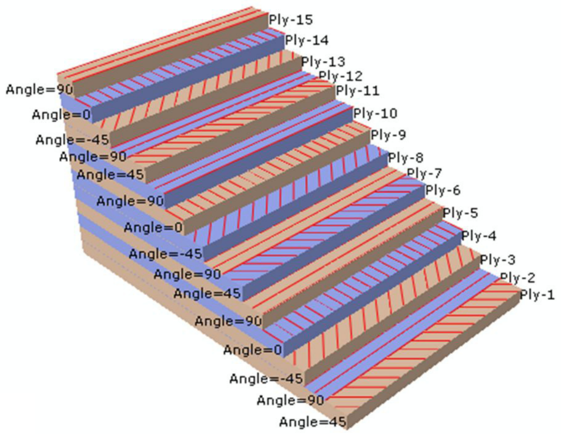


Fig. 4. Ply sequence and orientation of the composite test specimen.

Table 3. Ply sequence, material, thickness and orientation of the composite test specimen.

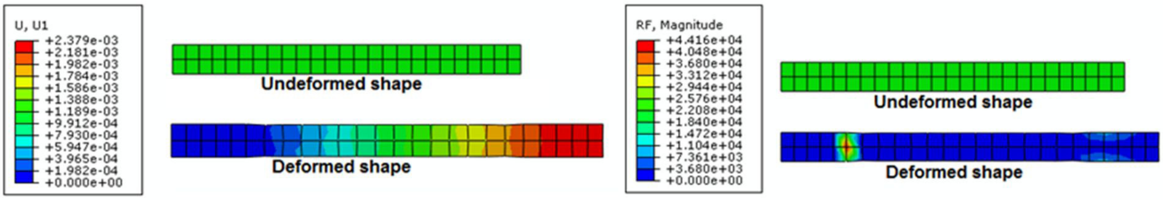
Ply No.	Material name	Thickness (m)	Orientation
Ply-1	Carbon fiber epoxy	0.217	45°
Ply-2	E-Glass fiber epoxy	0.00745	90°
Ply-3	Carbon fiber epoxy	0.217	-45°
Ply-4	Carbon fiber epoxy	0.217	0°
Ply-5	Carbon fiber epoxy	0.217	90°
Ply-6	Carbon fiber epoxy	0.217	45°
Ply-7	E-Glass fiber epoxy	0.00745	90°
Ply-8	Carbon fiber epoxy	0.217	-45°
Ply-9	Carbon fiber epoxy	0.217	0°
Ply-10	Carbon fiber epoxy	0.217	90°
Ply-11	Carbon fiber epoxy	0.217	45°
Ply-12	E-Glass fiber epoxy	0.00745	90°
Ply-13	Carbon fiber epoxy	0.217	-45°
Ply-14	Carbon fiber epoxy	0.217	0°
Ply-15	Carbon fiber epoxy	0.217	90°

5. Results and Discussion

This section focuses the analysis CFRP test specimen using different models and its validation with the experimental test results available in the literature (Avdic and Saha; 2011). The present modeling scheme was executed using shell conventional model, however for the purpose of assessment the solid model was also developed and it was found that the results from both the models are very close to each other as depicted and compared in Table 4 and Figure 5(a, b) and 6(a, b). As expected the maximum displacement occured at the free end while the reaction force was found to be maximum at the clamped end for both the models. However the small variation in the results could be associated due to the possible warpage of composite during its manufacturing process.

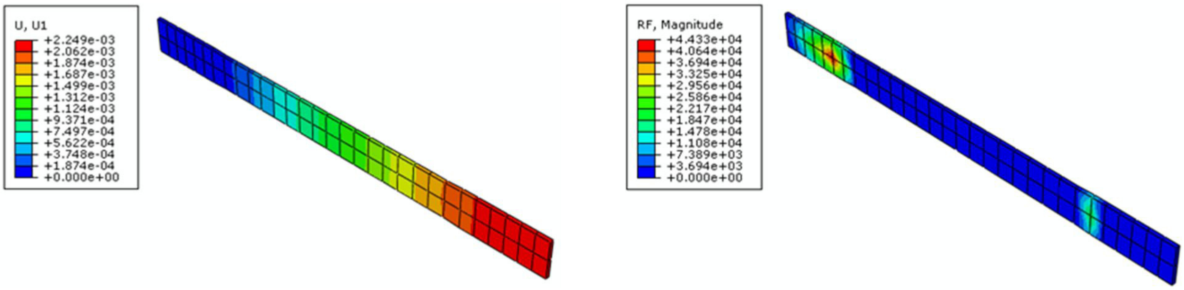
Table 4. Validation of the present model

Parameter	Results for Shell model		Results for Solid model	
	Present	Literature	Present	Literature
Reaction Force (KN)	44.16	44.27	44.33	44.30
Displacement (mm)	2.38	3.03	2.25	2.94
Strain (Major) %	1.12	1.69	1.10	1.65
Strain (Minor) %	-0.35	-0.32	-0.33	-0.5



(a) (b)

Fig.5. (a) Displacement and (b) Reaction force distribution over CFRP test specimen for shell model.



(a) (b)

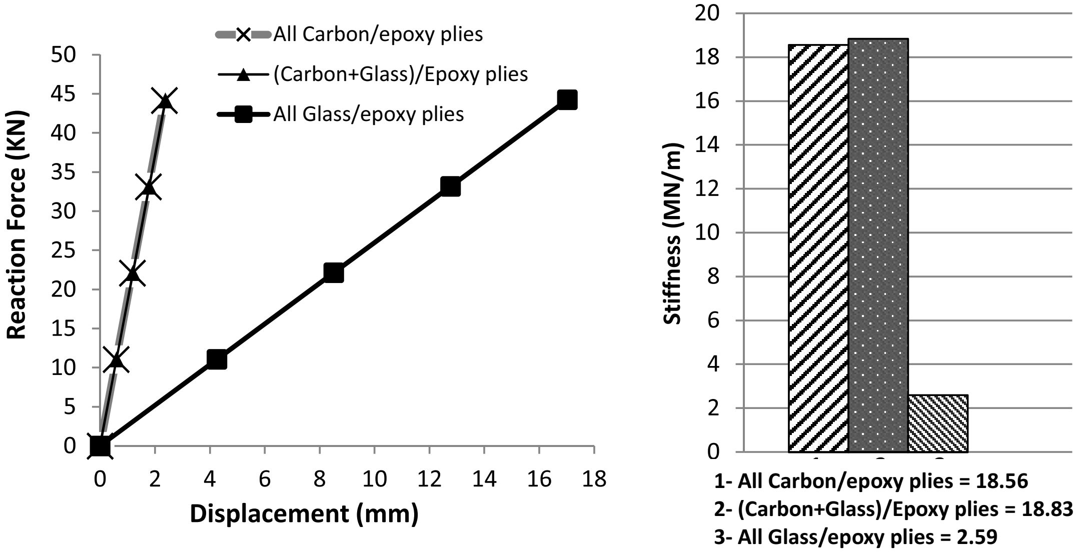
Fig. 6. (a) Displacement and (b) Reaction force distribution over CFRP test specimen for solid model.

6. Parametric Study

A parametric study has been carried out with the aim to explore the effectiveness of the model and to evaluate the influence of geometric and material parameters on the overall mechanical behaviour composite. Independent parameters such as ply orientation and selection of reinforcement material were varied and its effects on reaction force and material stiffness were examined thoroughly.

6.1. Effect of reinforcing material

Initially the analysis was carried on a 15 ply CFRP specimen containing 12 layers of carbon/epoxy and 3 layers of glass/epoxy plies and the results were compared with experimental data as shown in Table 4. Later in order to examine the effect of reinforcing material on the mechanical behaviour of composite the simulation was performed where all 15 plies were firstly considered to be made up of carbon/epoxy and secondly of glass/epoxy material. The comparisons for all three different materials were made in terms of reaction force and material stiffness and shown in Fig. 7(a) and 7(b) respectively. Due to high tensile modulus carbon/epoxy was found to have maximum stiffness while glass/epoxy the least. However no significant change in the stiffness was noticed when 12 ply carbon and 3 ply glass/epoxy material were compared against 15 ply of carbon/epoxy material. Contrary to this glass fiber due to its improved ductile property experienced the most displacement at same load when compared with carbon/epoxy material.

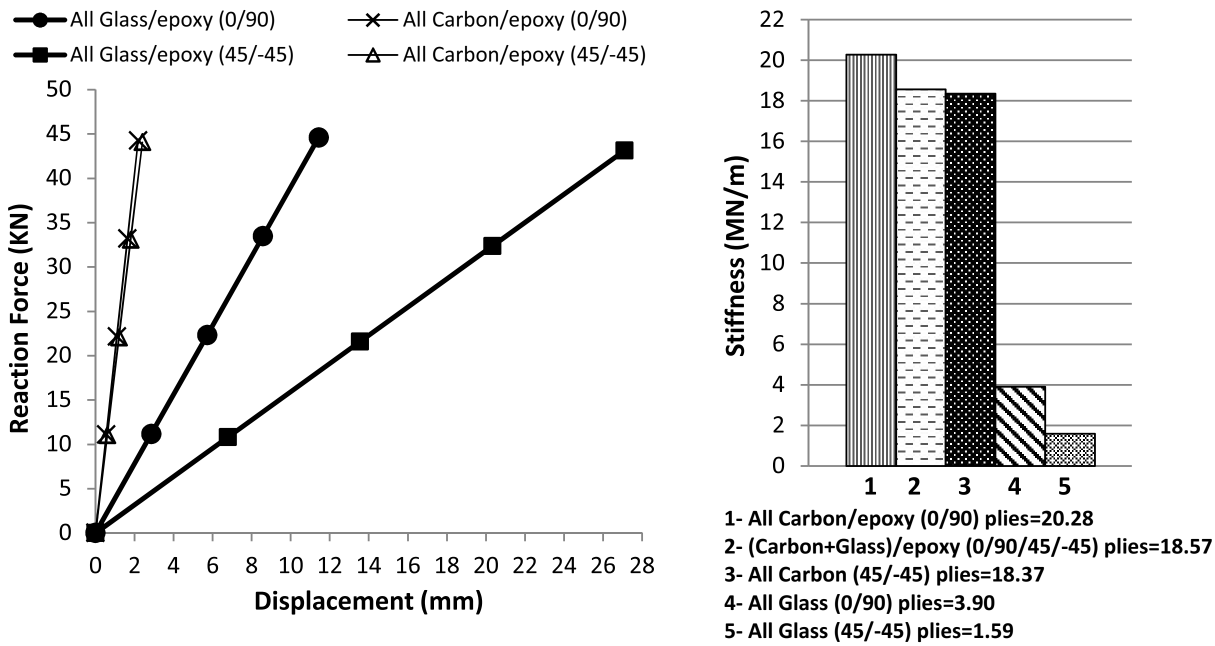


(a) (b)

Fig.7. (a) Reaction force vs. Displacement and (b) Stiffness comparisons for combinations of material.

6.2. Effect of ply orientation

The various combinations of ply orientations were simulated on tensile specimen with an aim to determine the best in the category for strength and stiffness as shown in Fig. 8(a, b). However it was observed that cross ply laminate for both carbon and glass/epoxy found to stiffer than angle ply whereas as far as displacement is concerned the angle ply laminates tends to deflect more than cross ply for almost same value of reaction force.



(a) (b)

Fig.8. (a) Reaction force vs. Displacement and (b) Stiffness comparisons for combinations of ply orientation

7. Conclusion

In this study the tensile test behavior of multilayer CFRP is simulated using finite element simulation software ABAQUS. Lamina properties for the material were calculated using rule of mixtures. Both shell and the solid models were developed, examined and validated regarding their feasibility and it was decided to go with shell model as it provide much flexibility over the solid model in terms computational cost. The multilayer CFRP behavior was simulated using S4R shell element rather than the solid elements as it saves computational time with accurate results. In order to replicate the real behavior of tensile test, load in the form surface traction is applied to the free end of specimen instead direct application of force. The displacement at the free end of the specimen was found to maximum and zero at the clamped end whereas the significant reaction force was noticed at the clamped end during simulation. The exhaustive parametric study which reveals the effect of reinforcing material and ply orientation on stiffness of the laminate was conducted and following significant conclusions were drawn: (i) Carbon rich laminates due to their increased tensile modulus were found to be stiffer than glass/epoxy laminates. (ii) Cross ply laminates have superior stiffness than angle ply laminates.The two most common types of defects associated with complicated manufacturing process of composites are fiber waviness and variation in thickness. These material imperfections may lead to premature failure of the composite laminate as the strain in that region may increase abruptly.

References

Avdic, A., Saha U.K., 2011. Simulating a tensile test of a carbon fiber composite test specimen in ABAQUS. M.Tech. Skövde Högskolan, Skövde, Sweden.

Dixit, A., Mali, H.S., 2013. Modelling techniques for predicting the mechanical properties of woven-fabric textile composites: A review. Mechanics of Composite Materials 49, 1-20.

Ochola R.O., Marcus K., Nurick G.N., Franz T., 2004. Mechanical behaviour of glass and carbon fibre reinforced composites at varying strain rates. Composite Structures 63, 455–467.

Sohna M.S., Hua X.Z., Kimb. J.K., Walker L., 2000. Impact damage characterization of carbon fiber/epoxy composites with multi-layer reinforcement, Composites: Part B 31, 681-691

Swenson D., and Ingraffea A., 1988. Modeling mixed-mode dynamic crack propagation using finite elements: Theory and applications. Computational Mechanics 3, 381–397.

Tong, L., Mouritz A. P., Bannister M. K., 2002. 3D Fiber Reinforced Polymer Composites, Elsevier, ISBN:0-08-043938-1.

Voigt, W., 1910. Lehrbuch der Kristallphysik. Teubner Leipzig.